RESEARCH HIGHLIGHT

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Effect of Snow and Ice on Exterior Ramp Navigation By Wheelchair Users

INTRODUCTION

Winter represents the most difficult season for people with mobility deficits. The difficulties include slips, falls, increased walking effort and snow-ice wheelchair obstructions. Considering the amount of time Canadians spend in winter, a remarkably small amount of literature exists on non-sporting winter activities. As a result, guidelines and standards for buildings are predominantly based on "dry-land" studies. In the case of residential access ramps, anecdotal feedback from wheelchair users identifies problems with winter accessibility due to the snow-ice surface properties.

Ramps and motorized lifts are the predominant means for wheelchair users to access buildings with raised doorways or multiple floors. However, many people with disabilities and the elderly stay in their homes rather than risk driving their wheelchairs outside when winter precipitation creates a potentially unsafe environment. This can lead to social isolation and related psychosocial problems.

This study provides better information on ramp design and ramp negotiation strategies, which will help educate wheelchair users, health professionals and builders to create a safe and accessible environment. The study is the first quantitative biomechanical analysis of wheelchair mobility on ramps under snow and ice conditions. Past qualitative and related research on winter wheelchair propulsion does not provide adequate information for decision-making regarding residential ramps during winter. This research provides evidence-based recommendations for builders, homeowners and people with disabilities when providing ramp-based access to homes during winter.

In addition to the information directly related to wheelchair mobility, this study demonstrates a viable quantitative analysis environment for future assessments of human interaction with exterior residential pathways in Canadian weather conditions.

Objectives

- Define biomechanical strategies for safely ascending and descending ramps with snow and snow-ice coverage using a wheelchair.
- Identify ramp slopes with snow and snow-ice coverage that are difficult or impossible to navigate.
- Obtain information on wheelchair user perceptions regarding ramp use in winter.

BACKGROUND

Manual wheelchair research on ramps has shown that young wheelchair users can ascend ramps up to a 1:8 slope, in dry controlled conditions. However, as noted by Rousseau et al.[1], the effects of snow, ice and rain have not been considered in these studies. Most studies reported increased physical demands as ramp slope increased past 1:20. Even at a

[1] Rousseau J, Aissaoui R, Bourbonnais D. Measuring the Effort Needed to Climb Access Ramps in a Manual Wheelchair. CMHC Research Highlight. 2005, April, 1-4.

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1:20 ramp slope, upper-extremity joint moments can exceed 30 per cent of the user's capacity. Kulig et al.[2] showed that shoulder forces and moments more than doubled when ascending an eight-degree incline with a wheelchair.

In the consumer literature, a qualitative analysis of nine powered wheelchairs while ascending and descending a 10-degree ramp slope with a 7.5-cm (3-in.) snow cover was performed by Smith[3]. All powered chairs were able to ascend and descend the ramp; however, control of mid- and front-wheel drive chairs was difficult. The investigator indicated that slopes greater than 10 degrees would be very difficult to negotiate in winter.

Research and consumer feedback on slopes steeper than 1:12 was not conclusive. Rousseau et al.[1] indicated that a 1:10 slope was a viable alternative since propulsive forces exerted on the wheelchair rims were not substantially different from forces at a 1:12 slope. However, Rousseau's study involved able-bodied subjects who may not have had the physical limitations found in typical wheelchair users (such as decreased range of motion, reduced balance, muscular dysfunction, and so on). No studies existed that provided biomechanical data on wheelchair propulsion in winter conditions.

Methodology

An adjustable, modular, wheelchair ramp was modified to provide a safe testing environment at 1:10, 1:12 and 1:16 grades. Ramp modifications included reinforcing the structure to reduce motion between modular ramp sections and to allow easy grade changes during testing, and adding a transition area from level ground to the ramp slope. Handrails were set to the maximum height of 38 inches. The second lower handrail was not installed since the railing would have potentially blocked markers from the cameras' view.

A self-braking belay descender device and mountain-climbing rope were added as a safety tether system, which could be engaged if an unsafe condition occurred during data collection. Additional strapping was affixed to the clients' wheelchairs at the front and rear to provide secure attachment points for the safety rope. A carabineer clip secured the wheelchair strapping to the safety rope. Since the tether was attached to the wheelchair, a lap belt was fitted to each subject and wheelchair to keep the subject in the wheelchair in the event that the safety line engaged.

All testing took place at the National Research Council, Centre for Surface Transportation Technology, Climatic Engineering and Testing Division (Ottawa). This facility is Canada's largest climatic chamber. The facility can produce temperatures ranging from -51°C to +55°C and includes a full suite of instrumentation and 190 channels for data recording to track performance under conditions of snow, rain, freezing rain, ice, and fog—and even a combination of those conditions.

As this was the first group to perform quantitative motion analysis in the Climate Lab, various adaptations were necessary. Space in the control room was made available to install the Vicon Motion Analysis computer and hardware (used to measure limb orientation during motion), prepare the test subjects and provide a warm area for subjects to wait between trials. Ten Vicon motion capture cameras were positioned around the ramp, within the climate chamber.

Eleven manual wheelchair users who typically self-propel their wheelchairs in winter were recruited through The Ottawa Hospital Rehabilitation Centre. After the subjects confirmed they understood the project protocol, all completed a consent form and a questionnaire about their experiences with wheelchair propulsion in winter.

Two winter scenarios were evaluated: packed snow and "packed snow with a freezing rain cover and traction grit." Subjects navigated the ramp at each slope (1:10, 1:12 and 1:16) and at each condition. Motion tracking (Vicon Motion Analysis System), digital video and questionnaire data were collected to assess biomechanics and subject perceptions.

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[2] Kulig K, Rao S, Mulroy S, Newsam C, Gronley, JoAnne K, Bontrager E, Perry J. Shoulder Joint Kinetics During the Push Phase of Wheelchair Propulsion. Clinical Orthopaedics and Related Research. 1998; (354): 132-143.

[3] Smith L. Weathering the Winter in a Wheelchair. Rehab Management (http://www.rehabpub.com/ltrehab/10112000/4.asp). 2000; October/November.

Figure 1 Ramp ascent on ice-grit using handrails.

Findings

This study confirms the need for research on mobility in winter. While research on this broad topic is in its infancy, the focus of this study on ramp negotiation in snow and ice-grit conditions has provided insight and knowledge to help improve mobility in this target area.

For people who must manually propel a wheelchair through snow and ice conditions, various biomechanical and environmental factors influence successful ramp negotiation. Outcomes from this study confirm that, using standard propulsion techniques, independence cannot be assumed for all conditions and ramp grades that are accepted under current building codes.

In terms of ramp grade, all subjects were able to complete the ice-grit conditions independently at all ramp slopes. The ice-covered snow created a firm, but uneven, surface that eliminated issues such as the wheels becoming embedded in the snow. Sufficient grit was used to provide a safe environment for walking and wheeling on the surface. However, subjective feedback from the participants indicated that insufficient grit, or other friction-enhancing material, are typically applied to exterior ramps. This creates an unsafe condition or inaccessible ramp (due to wheel slip on the ice).

Even with sufficient grit, the more active subjects frequently had wheel slip issues during ascent at the 1:10 and 1:12 slopes (that is, stronger propulsive motion surpasses wheel-ice-grit friction). These subjects typically used a two-handrail pull approach to reinitiate motion and then reverted to standard propulsion. Recommendations could be made to use two-handrail propulsion under ice conditions since friction issues are resolved (that is, no propulsive force on wheel rims), control of wheelchair trajectory is improved, and stronger propulsive forces can be generated.

Snow conditions produced a much different scenario across ramp grades. The 1:10 grade was insurmountable for many subjects without assistance. The main issue was the front wheels becoming embedded in the snow. Without the ability to lean back, clear the front wheels from the snow and propel the wheelchair forward (at the steeper 1:10 grade), external assistance to clear the wheels from the rut was the only way to reinitiate forward progression.

Interestingly, no relationship was found between front wheel size and success on snow conditions. Subjects using wheelchairs with larger/wider front wheels had the same problems as people using smaller wheels. While therapists prescribing wheelchairs may intuitively recommend wider front wheels for people who propel their manual wheelchairs in winter, the results from this study indicate that a much larger increase in dimensions, as compared with typical front casters on the market, would be required to have a substantial effect. Further research is required to understand the wheel dimension threshold beyond which a positive effect would be found.

An important element to consider for snow and exterior ramps is the transition area from level ground to incline and areas where movement is initiated. Even with snow maintenance between trials (that is, redistributing and tamping the snow onto the ramp), the snow rapidly became softer over the initial 2-m (6.6-ft.) transition area. The impact of the front wheels on the packed snow, as the wheelchair moved from level ground onto the ramp, broke the packed snow until it was unable to maintain a solid base. As the front wheels became embedded in ruts in the ramp surface, spinning of the rear wheels continued to erode the packed surface. A similar, but less severe, situation occurred at the transition from incline to level surface at the top of the ramp. While this softer snow was not a factor in this study, the implications for longer ramps with transitional areas in the middle should be considered in future work.

The "soft snow area" was consistent with qualitative feedback from wheelchair users who frequently mention difficulties with this transitional area at the bottom of exterior ramps. In most cases, even if the level ground area is relatively clear of snow, accumulation of soft snow at the bottom of exterior ramps stops forward progression, thereby removing any

momentum that can facilitate ramp ascent. Since this surface condition was unavoidable, even in a controlled environment, new approaches should be considered for ramp designs, ramp maintenance standards and client practices.

Subjects who were unable to independently navigate the soft initial transition area started one quarter of the way up the ramp. Even when avoiding the bottom transition area, most subjects had difficulty initiating and propelling up the 1:10 slope, with two subjects being unable to complete the task and many requiring assistance from the research team to free the front wheels from the snow and reposition the wheelchair up the ramp on a more solid section. While mild difficulties were experienced in snow at the 1:12 and 1:16 grades, participants were able to navigate these grades independently.

Seven strategies were used for ramp navigation: standard propulsion (pushing on wheel rims), use of both handrails (pulling up on ascent or slowing down chair on descent), placement of one hand on handrail and one on opposite wheel to coast (wheelchair rolling down ramp without user propulsion), wheelie with user pushing on rims, wheelie while coasting down ramp, and backwards ramp ascent using both handrails. Typically, combinations of strategies were used; for example, two handrails to initiate movement, standard propulsion until wheelchair progression was halted as a result of front wheel obstruction, one handrail to clear front wheels, and a combination of standard and two-handrail propulsion for the top ramp section.

Figure 2 Backwards ramp ascent.

One subject successfully ascended the ramp backwards, at all grades, by reaching back and pushing on both handrails. Since this subject was at a moderate functional level, the backwards strategy could be applicable for most people who manually propel their wheelchair in winter. The shoulder and trunk ranges of motion were also typical. More research on backwards ascent is warranted to verify how this approach can be used by lower-functioning wheelchair users and to determine if wheelchair and environmental issues exist when extended to a larger population.

CONCLUSIONS

- Based on the slightly lower number of difficulties and shortest times to ascend the ramp, the 1:16 grade is preferred for winter ramp navigation.
- While sufficient evidence was not obtained to recommend removal of 1:10 ramp grades from exterior building standards, snow accumulation on ramps at 1:10 grade will render the ramp inaccessible for many wheelchair users who do not have external assistance.
- For snow conditions, the transition area from level ground to the first 2 m (6.6 ft.) of ramp incline were the most difficult to traverse, for both ascent and descent. Guidelines for design and maintenance of this area are recommended to improve accessibility and independence.
- For ice-grit ramp navigation, two-handrail propulsion is a preferred strategy, as it enhances trajectory control and reduces the potential for wheel slip problems.
- Backwards ramp ascent for snow conditions should be considered for people with sufficient shoulder and trunk ranges of motion, although further research should be performed to verify that the successful outcomes can be generalized beyond the single subject results in this study.
- Two handrails are recommended for exterior ramps, for both propulsion and wheelchair extraction from ruts and other snow-related obstacles. Handrail design issues are important, considering the enhanced roles for descent control, obstacle extraction and propulsion. Important factors include allowing unobstructed grip throughout the ramp length (with no posts blocking the hand when using the rails to control descent), ensuring handrails that are free of snow and ice, and so on.
- For ice ramp navigation, the amount of grit required and the effective time (that is, time to when grit becomes embedded in snow-ice and therefore much less effective) should be addressed in further research.
- Front wheels typically available with manual wheelchairs are not designed for soft snow conditions. Few options exist that attempt to address this need; therefore, further research in this area is warranted.

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